



DRIVE  
SYSTEM  
DESIGN



## Gearing Up for Lower Cost Electric Drives

Novel Methods for Analysing Integrated Electric Powertrains

The 6<sup>th</sup> International Electric vehicle Expo – 9<sup>th</sup> May 2019

Lee M. Sykes

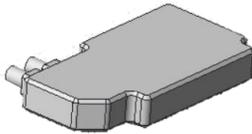
[www.drivesystemdesign.com](http://www.drivesystemdesign.com)



# Component trade-offs affecting system cost and efficiency

## Increased motor speed

Inverter



Motor



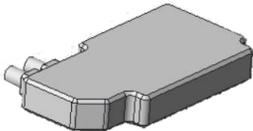
Transmission



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Motor



Transmission



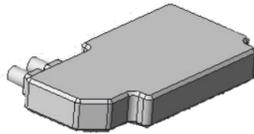
Reduced cost ✓□

Reduced Mass ✓□

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## Increased motor speed

Inverter



Increased cost



Reduced  
Efficiency



Motor



Reduced cost



Reduced Mass



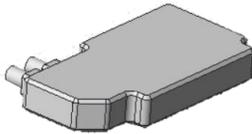
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Reduced  
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Reduced cost



Reduced Mass



Transmission



Increased cost

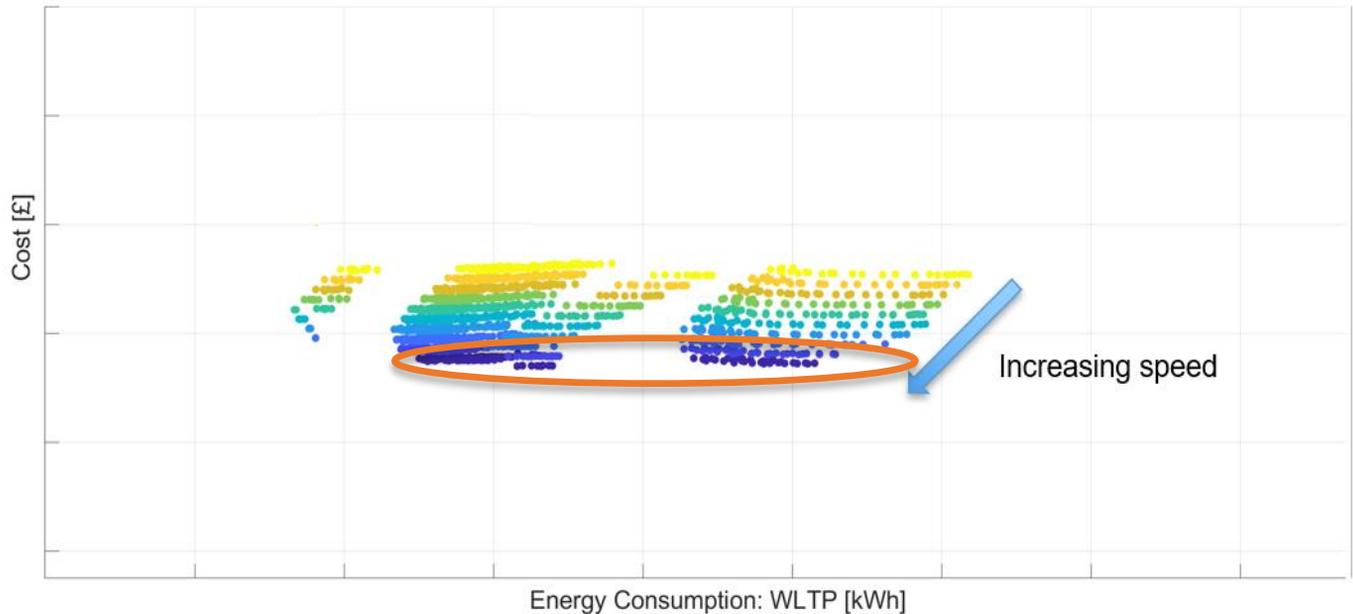


Reduced  
Efficiency



# Component trade-offs affecting system cost and efficiency

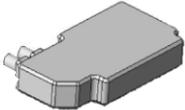
## Cost against energy consumption



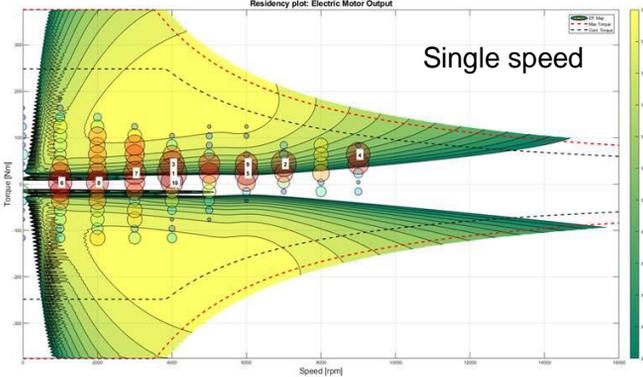
# Component trade-offs affecting system cost and efficiency

## Single / Multi speed transmission

Inverter



Motor



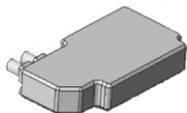
Transmission



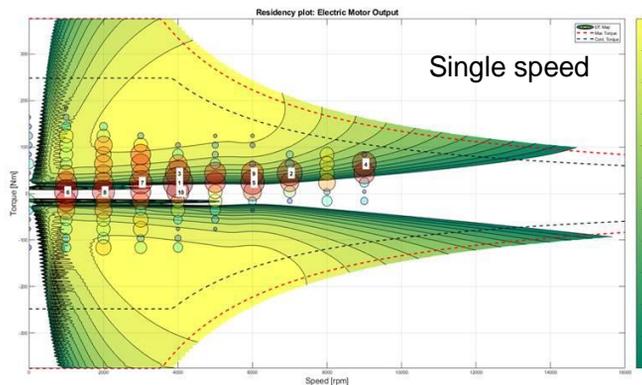
# Component trade-offs affecting system cost and efficiency

## Single / Multi speed transmission

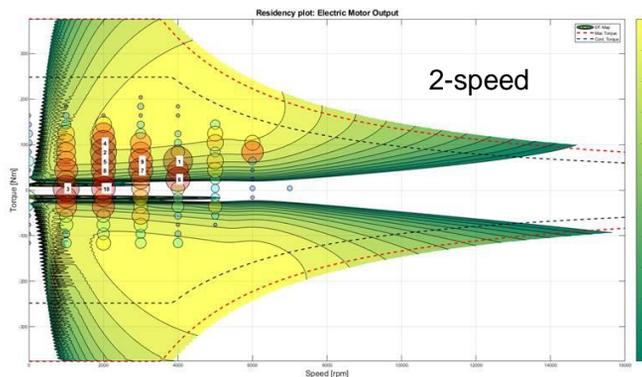
Inverter



Motor



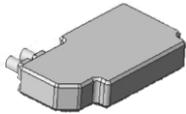
Transmission



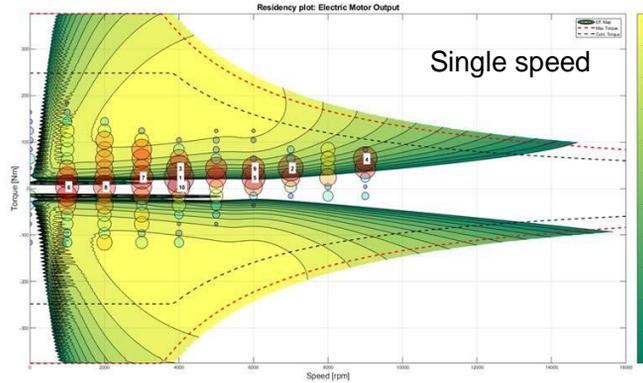
# Component trade-offs affecting system cost and efficiency

## Single / Multi speed transmission

Inverter



Motor



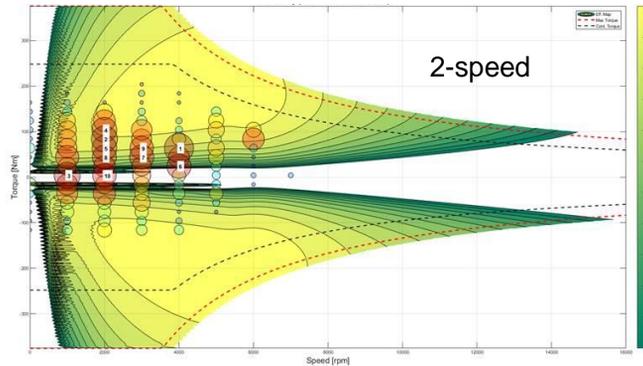
Transmission



Reduced Switching Frequency



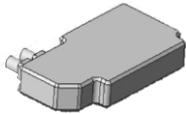
Reduced switching loss



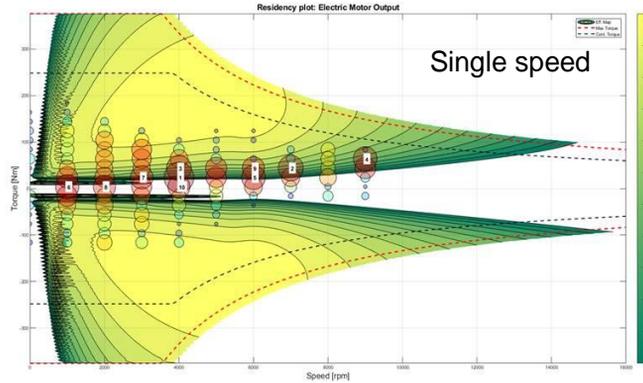
# Component trade-offs affecting system cost and efficiency

## Single / Multi speed transmission

Inverter



Motor



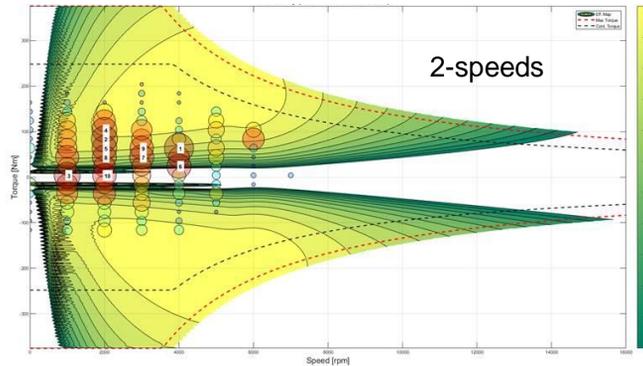
Transmission



Reduced Switching Frequency



Reduced switching loss



Increased cost



Reduced Efficiency



# Component trade-offs affecting system cost and efficiency

## Effect of motor current on inverter

Motor



### Increased motor current

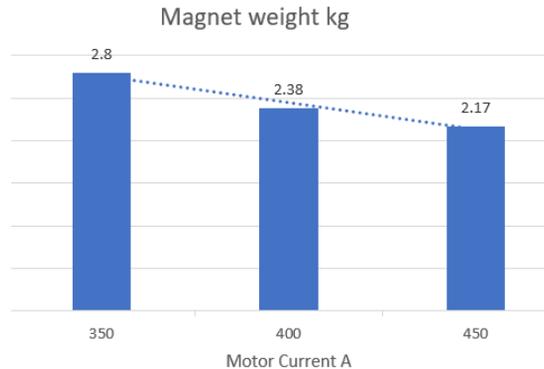
Reduced cost ✓□

Reduced magnet volume ✓□

# Component trade-offs affecting system cost and efficiency

## Effect of motor current on inverter

Motor



Increased motor current

Reduced cost ✓ □

Reduced magnet volume ✓ □

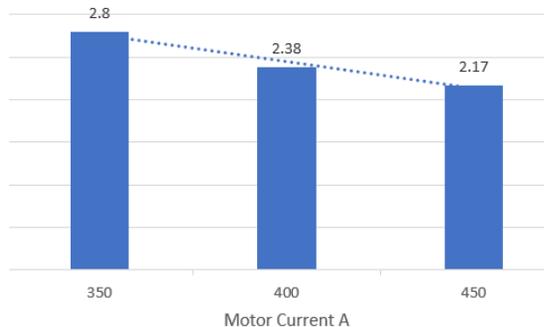
# Component trade-offs affecting system cost and efficiency

## Effect of motor current on inverter

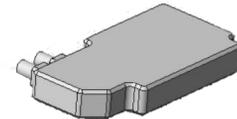
Motor



Magnet weight kg



Inverter



Increased motor current

Reduced cost

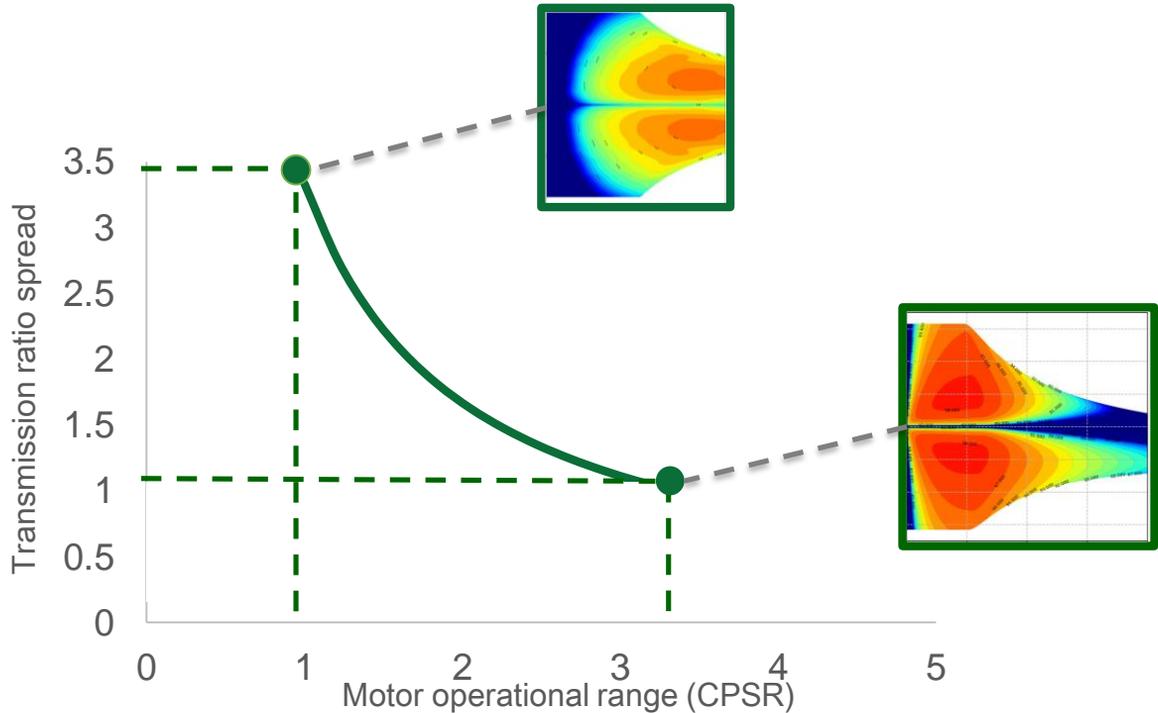
Reduced magnet volume

Increased cost

Reduced efficiency

# Component trade-offs affecting system cost and efficiency

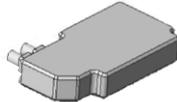
## Effect of motor type on transmission matching



## Opportunities



- Optimised speed / gear ratio
- Optimal topology
- Optimised current
- Type



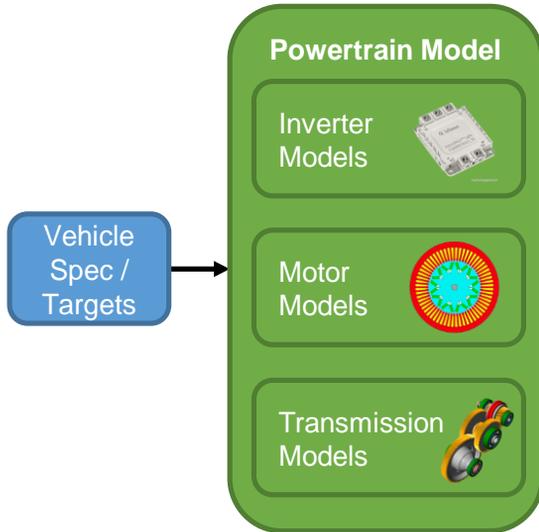
- IGBT and SiC
- Switching strategy



- Single / multi speeds
- Different types / configurations

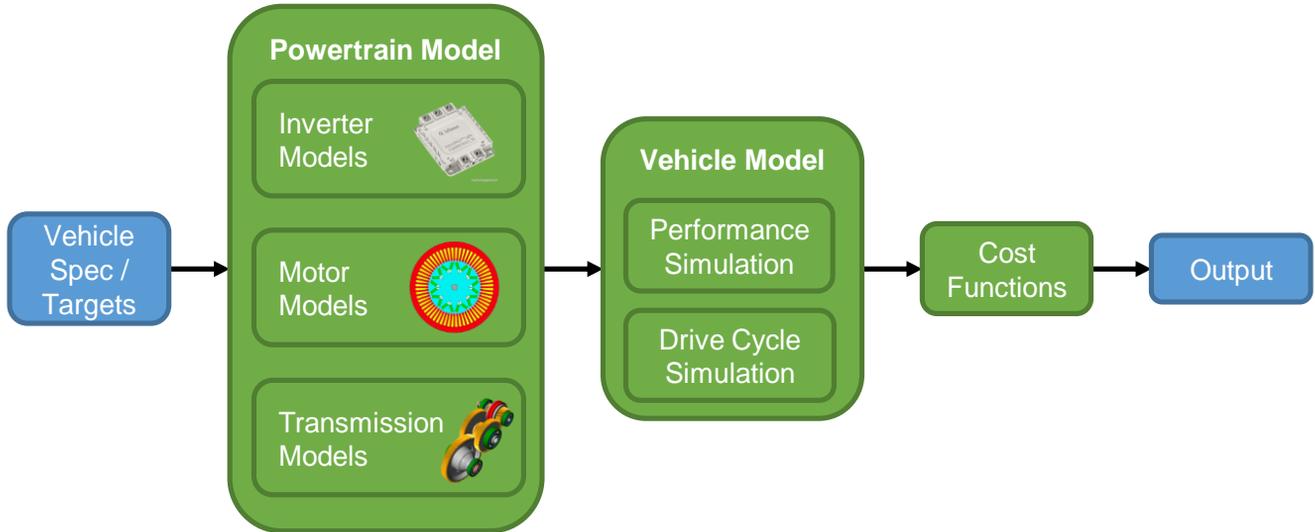
# What is the DSD process?

1,000s of powertrain variants



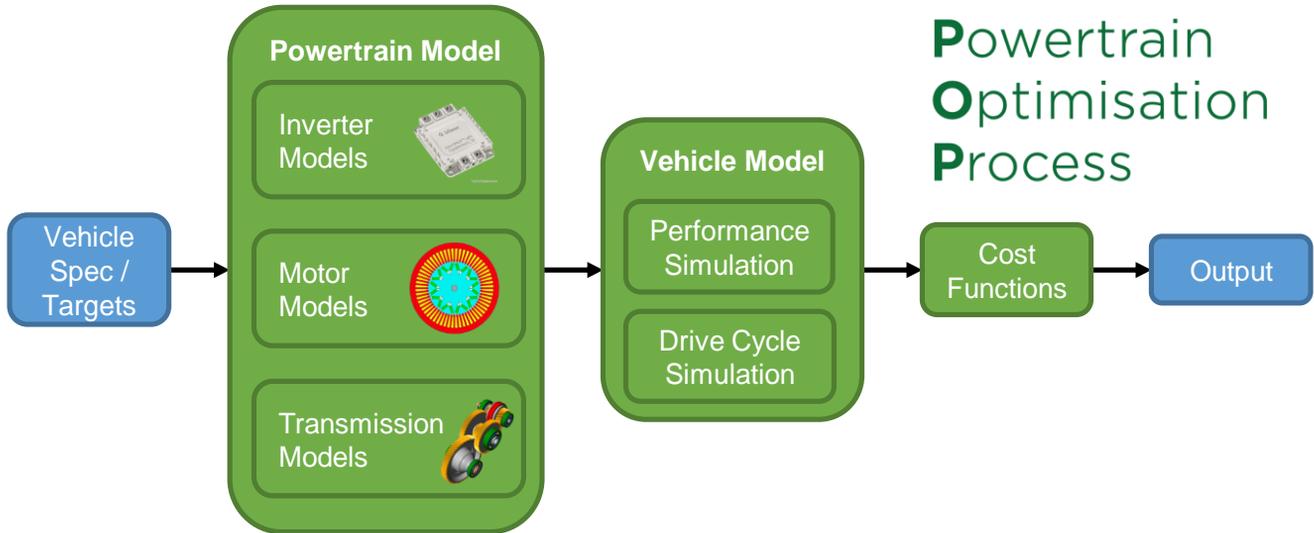
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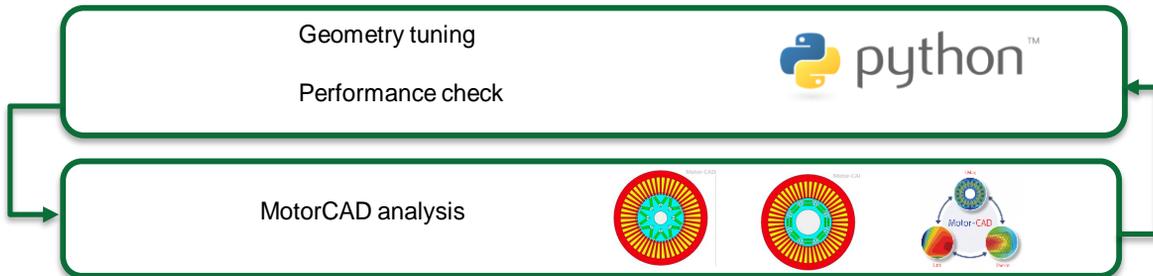


# What is the DSD process?

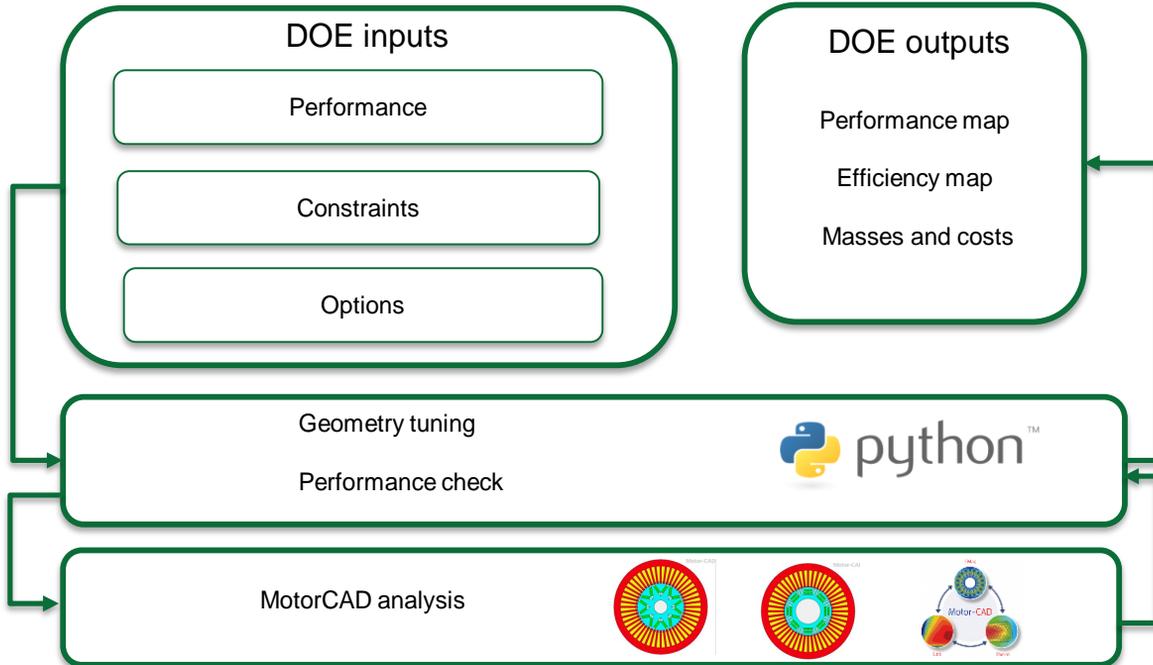
1,000s of powertrain variants



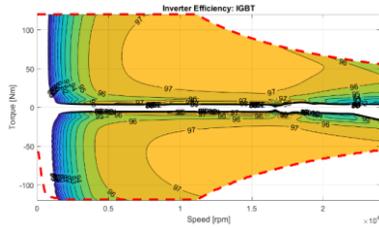
electrified  
**P**owertrain  
**O**ptimisation  
**P**rocess



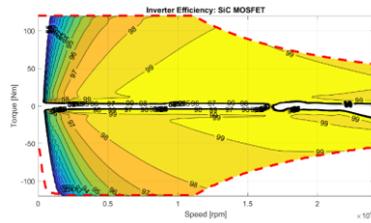
# Motor modelling



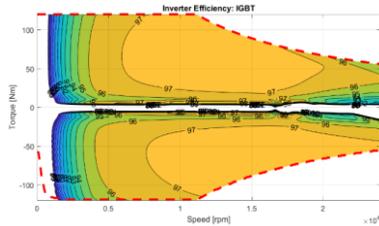
## IGBT



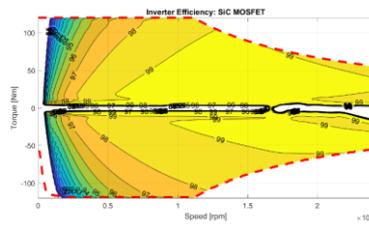
## Silicon Carbide (SiC)



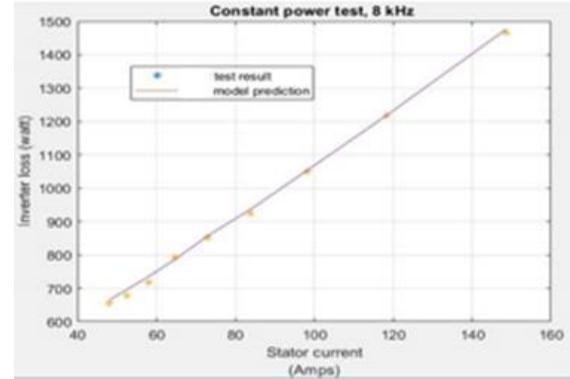
## IGBT



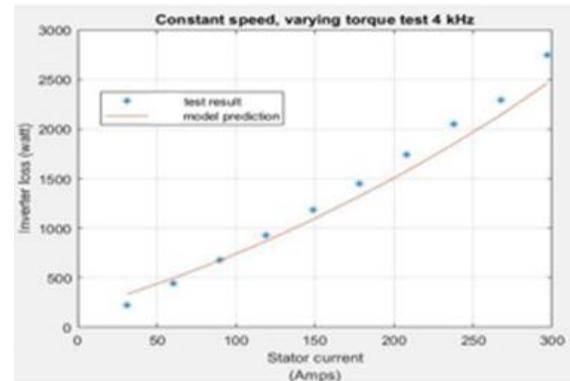
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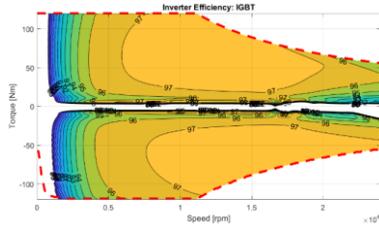
## Test 1



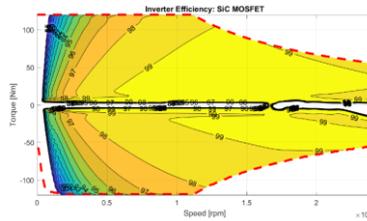
## Test 6



## IGBT



## Silicon Carbide (SiC)



## Losses



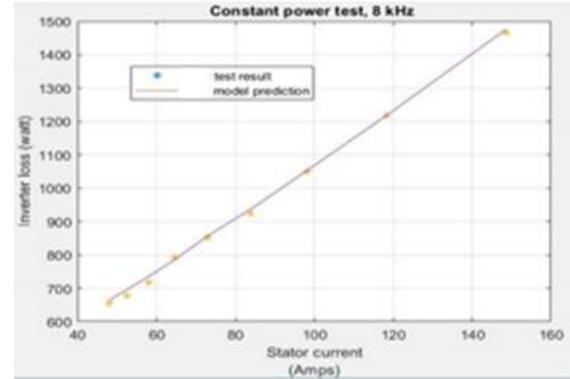
### IGBT Losses



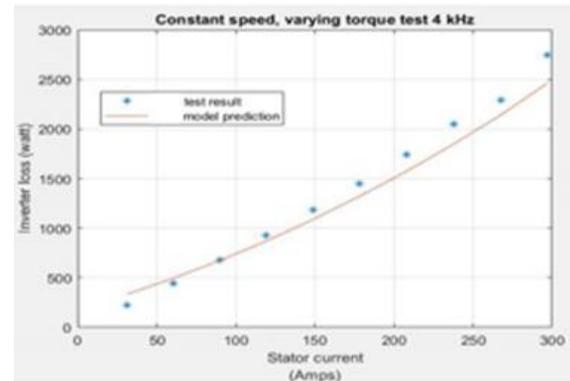
### SiC Losses



## Test 1



## Test 6



# Transmission modelling

2-Stage



3-Stage



Planetary



Multi-Speed

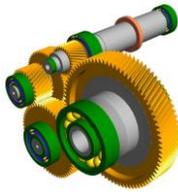


# Transmission modelling

2-Stage



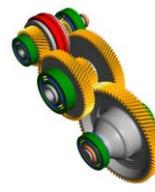
3-Stage



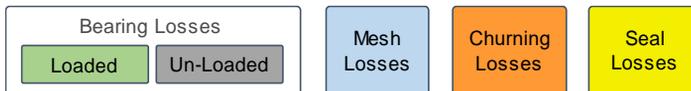
Planetary



Multi-Speed



## Losses



# Transmission modelling

2-Stage



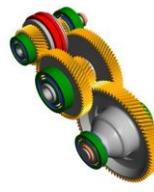
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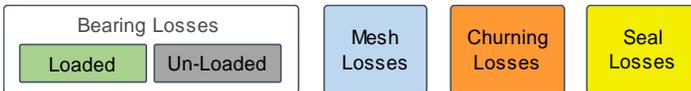
Planetary



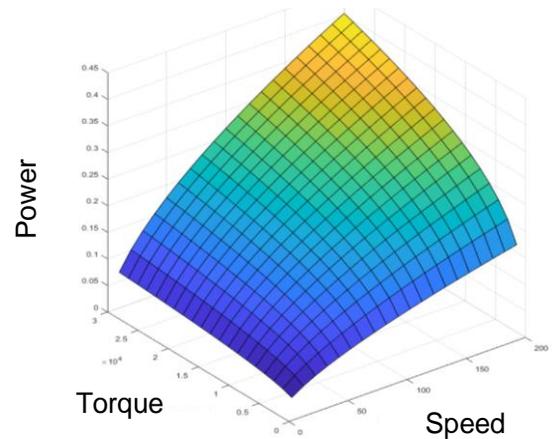
Multi-Speed



## Losses



## Efficiency map



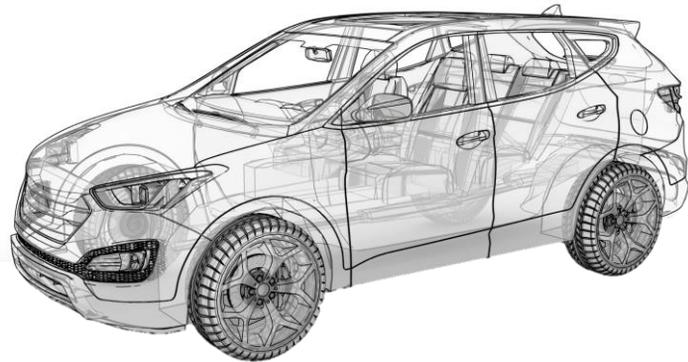
## Case study vehicle

### Specification

Premium SUV  
Pure EV

### Performance Targets

Range  
Top Speed  
Acceleration



## Case study vehicle

### Specification

Premium SUV  
Pure EV

### Performance Targets

Range  
Top Speed  
Acceleration

Transmission Variants	
Single speed	2-speeds

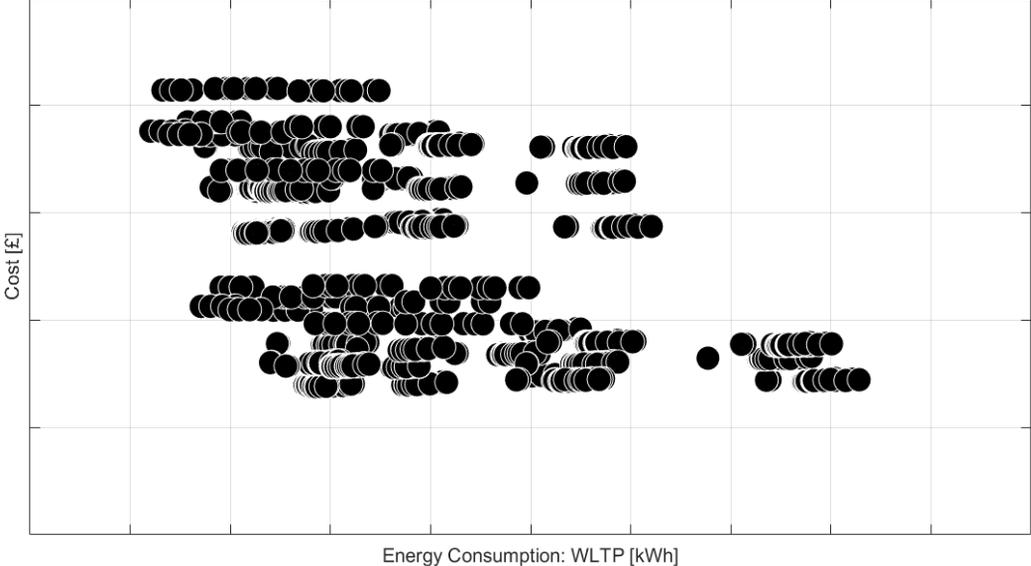
  

Motor Variants	
160 kW Fixed (V shape, U shape)	6, 8, 10 poles

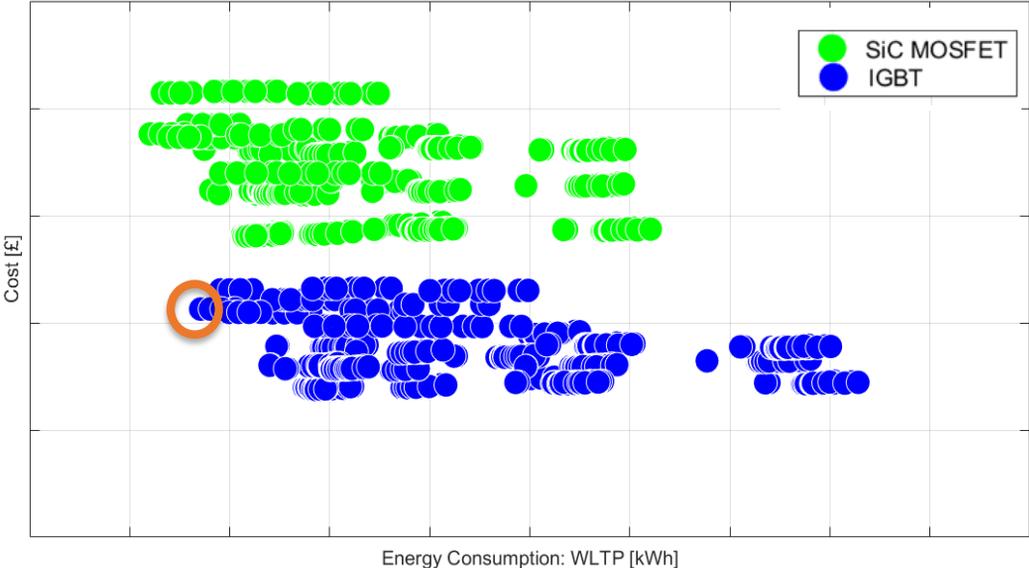
Inverter Variants	
IGBT	SiC MOSFET

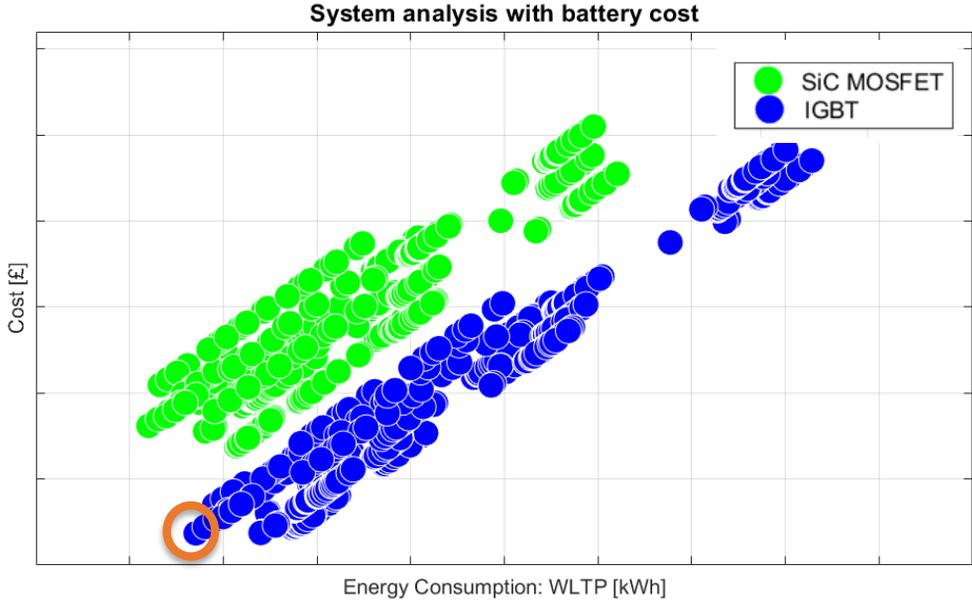
# Results

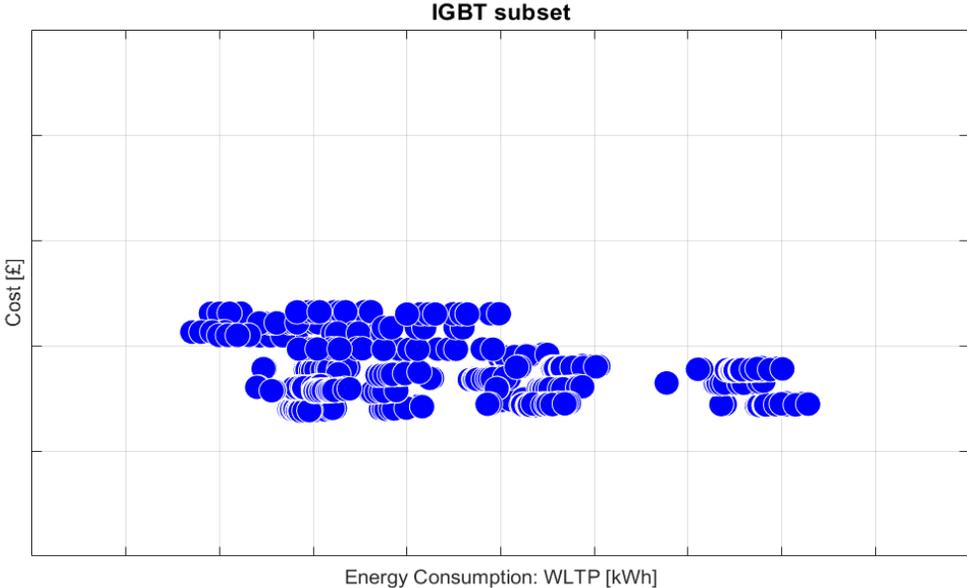


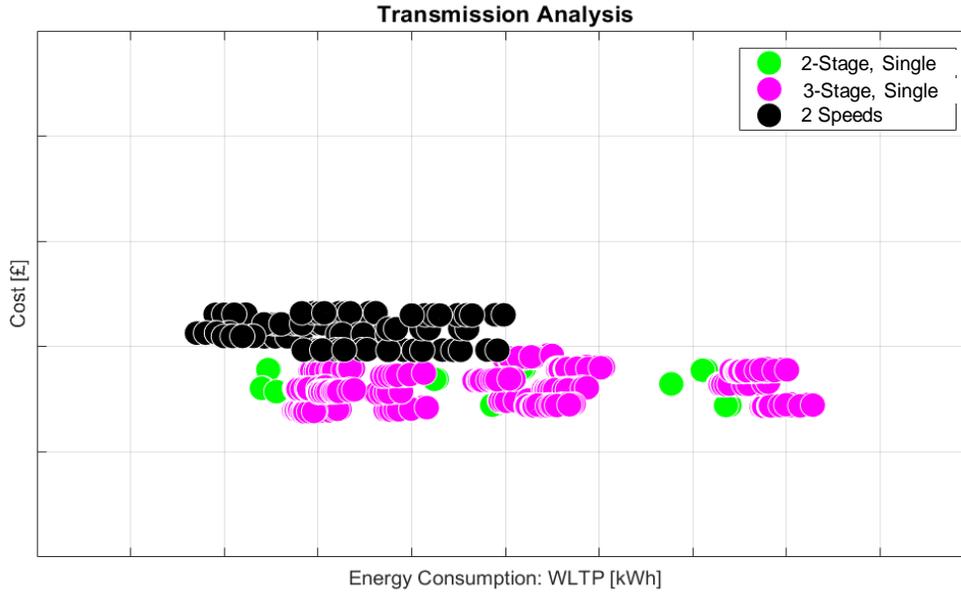


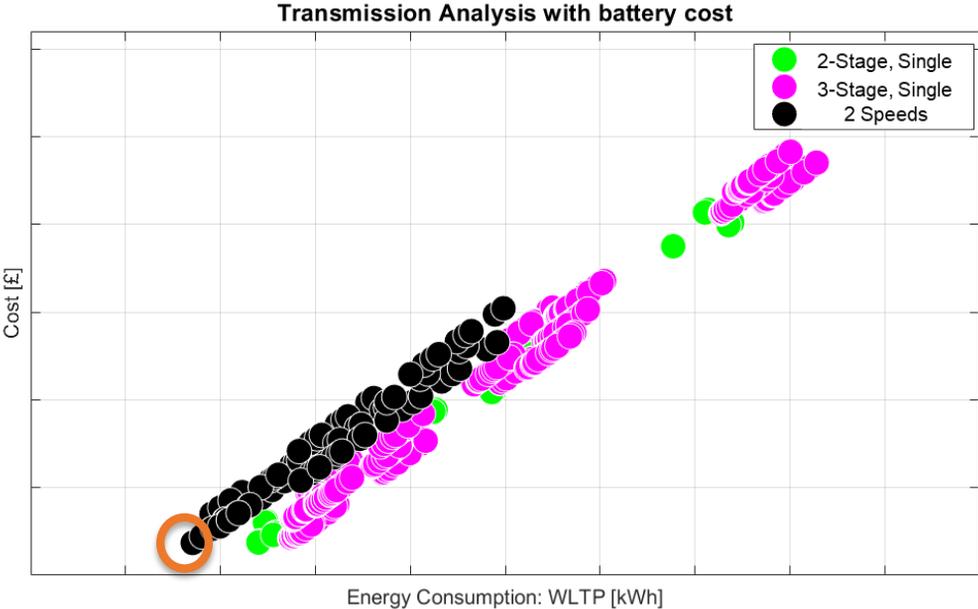
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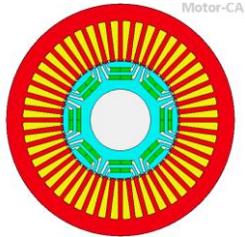
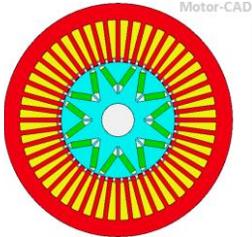
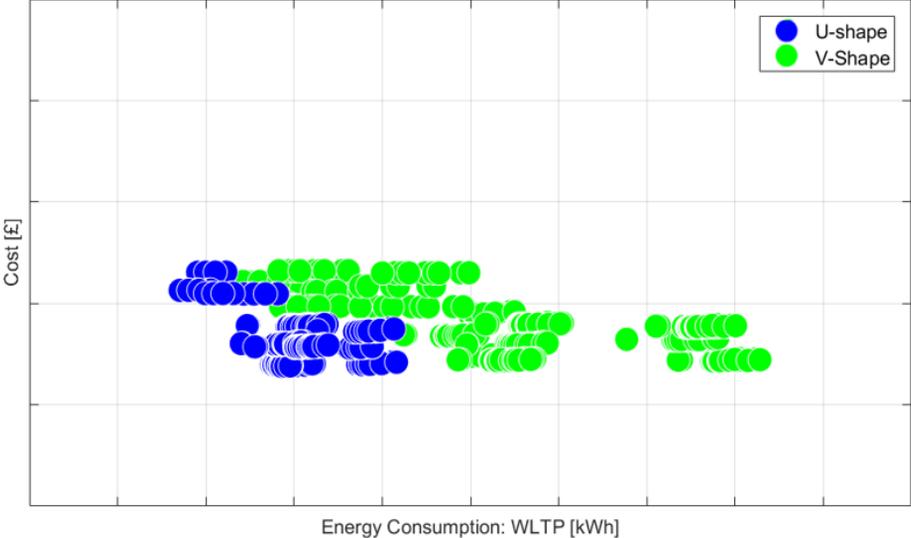


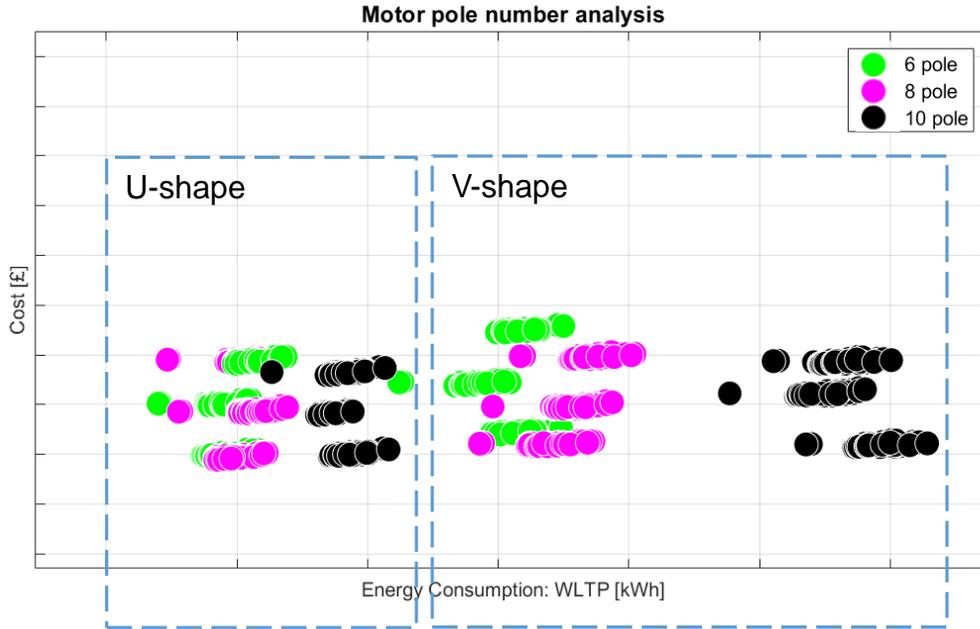




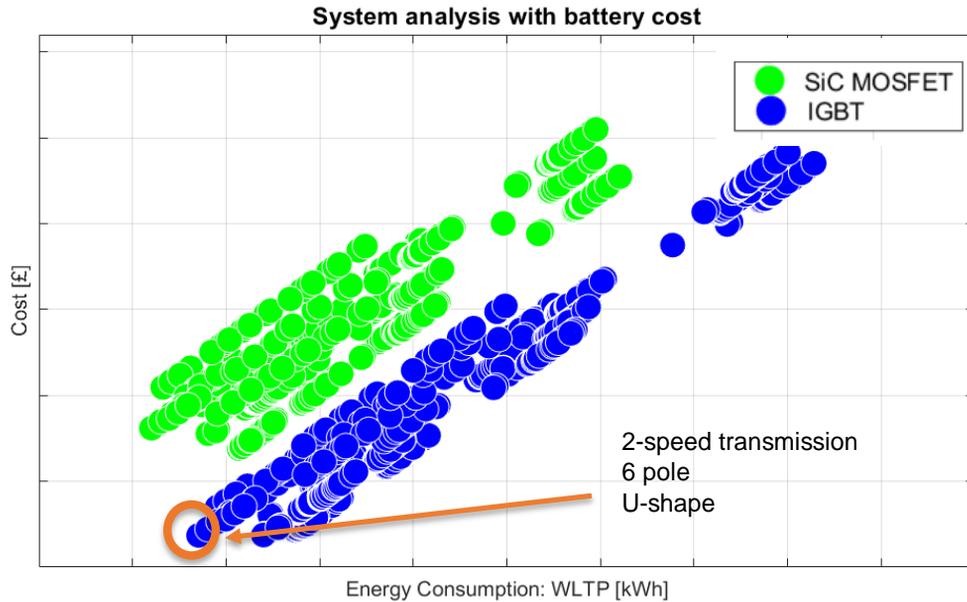


### Motor topology analysis

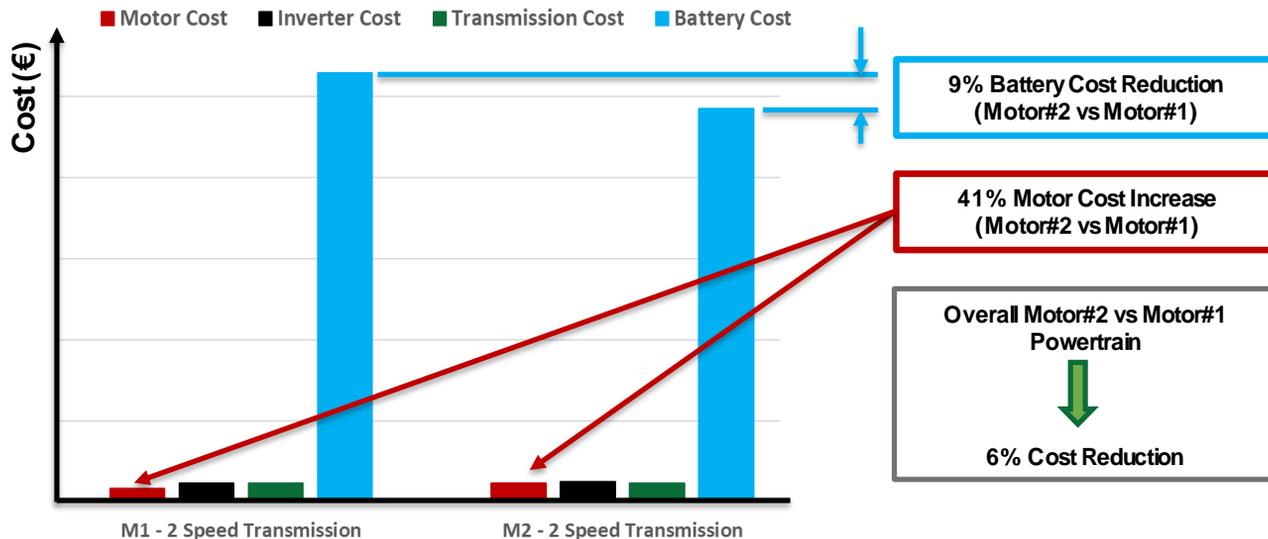








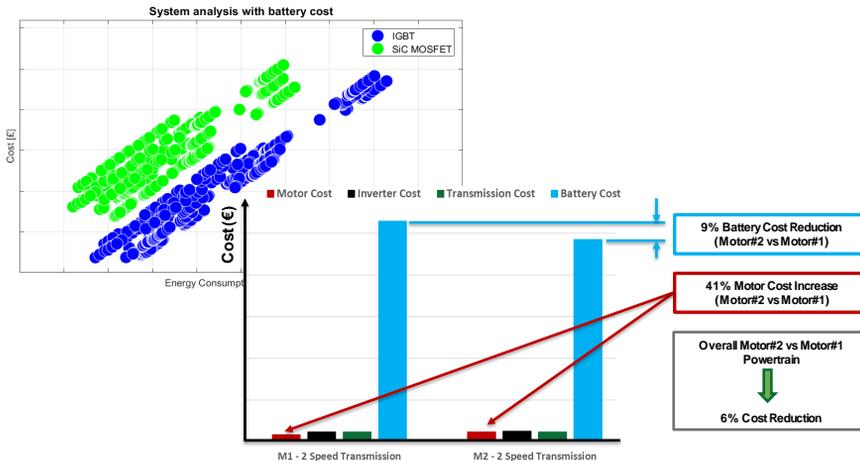
## What can this mean in terms of whole propulsion system cost?



# An accurate system analysis tool for rapid optimisation of electric / electrified powertrains

- Rapid component model creation
- Design space mapping
- Evaluating complex trade-offs
- Quantifying total system configuration for trade-off analysis and defining lowest cost to achieve vehicle attributes
- Weight cost function to account for different markets and applications

## electrified Powertrain Optimisation Process



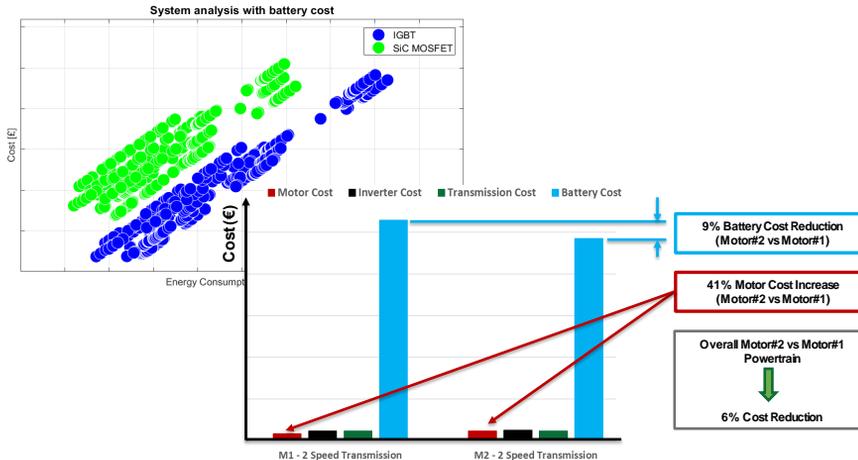
## Where next?

- Further variant options
- Hybrid vehicles

# An accurate system analysis tool for rapid optimisation of electric / electrified powertrains

- Thank you!
- 고맙습니다

## electrified Powertrain Optimisation Process





# DRIVE SYSTEM DESIGN



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